Is the governance of the Thau coastal lagoon ready to face climate change impacts?

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Title

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Abstract

The present paper provides a reflection on threats to integrated management of the Thau coastal lagoon due to climate change and the multi-scalar water scarcity adaptation strategy. This study proposes first to depict the Thau water governance assessed through a water use and social network analysis and its capacity to manage water quality. Next, this paper provides a downscaled study on the climate change impacts on the hydrological budget of the entire Thau catchment in 2041-2070 compared with the 1971-2000 reference period, a methodology developed during the CLIMB EU

research program. Following local climate change impacts, the importation of a new water resource to secure water uses is presented in regards to the capacity of local water governance to maintain coherence between integrated land planning and integrated water management planning based on water quality issues of the Thau coastal lagoon. The study underlines that although the water uses are currently secured thanks to the regional transfer of water, they are not coherent with local water management and create new vulnerabilities in the context of climate change. Moreover, the regional decision to end financial support for the more efficient, existing network for the water quality survey of regional coastal lagoons breaks up the local water governance. This paper demonstrates why keeping this network would have been absolutely necessary for encouraging a governance capable of proposing sustainable solutions to water quality challenges induced by climate change.

Keywords: climate change, integrated coastal management, hydrology, water governance

Highlights

- Climate change will increase temperature and decrease runoff in the Thau catchment
- Climate change challenges for local water uses are not perceived by local stakeholders
- Regional water management provides security for domestic use including tourism, and irrigation
- Regional water management increases the vulnerability of local water governance
- CLIMB EU FP7 project, CLIWASEC cluster, multidisciplinary analyses

Introduction

According to the IPCC climate model projections, Mediterranean countries are at high risk for pronounced susceptibility to changes in temperature in the hydrological budget and in the occurrence and magnitude of extreme conditions (IPCC, 2007; Giorgi and Lionello, 2008). Moreover, the increase in temperature of marine waters and its interaction with acidification may induce an amplification of eutrophication and hypoxia (Bijma et al., 2013).

It can be foreseen that the changes in the hydrologic cycle will give rise to an increasing potential for conflicts (Ludwig et al., 2011), or at least rivalries (Bressers and Kuks, 2004; Aubin, 2008; La Jeunesse et al., 2013), and possible tensions among the political and economic actors. To provide expertise and adaptation strategies, multidisciplinary research is needed to tackle the multi-facet complexity of climate change impacts on water resources (Quevauviller et al., 2012) a fortiori in the Mediterranean (Santos et al., 2014). In this context, the cluster of three EU projects CLIWASEC is

tackling the 'climate change – water – security' nexus. One of those, the CLIMB project, is focusing on inter-linkages and interdisciplinary analyses around the quantification of uncertainties in climate change impact and risk assessment (Ludwig et al., 2010).

Several empirical and simulation studies support the idea of increased eutrophication with climate change which contradict the expectations of reductions in nutrient loading from catchments in drier climates and greater stability of the water column in warmer climates (IPCC, 2007). Because of the already high anthropogenic pressures coming from both coastal and continental areas, transitional waters and a fortiori coastal lagoons, as semi-enclosed ponds, are the ecosystems particularly exposed to the impacts of climate change.

Following this list of impacts, effective adaptation measures require multi-disciplinary preparation and efficient water governance (Ostrom, 1990). *"Governance refers to all processes of governing […], it focuses not only on the State and its institutions but also the creation of rule and order in social practices"* (Bevir, 2013). Thus, governance is a mix of procedures (hierarchical, networked, or market-oriented) which involves public and private stakeholders in the management of an issue of public interest. The focus here is on the local networks of public and private water users and managers and the ways these stakeholders manage water-related issues and problems. In particular, transitional waters at the confluence of continental and marine issues are complex ecosystems with important anthropogenic pressures sometimes exacerbated by inappropriate management in diverse chains of cause-effect relationships (Newton et al., 2014).

The European Union started to define rules for Integrated Coastal Zone Management (ICZM, Cicin-Sain and Knecht, 1998) first through the Water Framework Directive (WFD), which covers the transitional and coastal waters up to 1 nautical mile from the continental baseline. The ICZM has been completed for marine waters by a marine policy initiated in 2008 with its environmental part represented by the Marine Strategy Framework Directive (Borja et al., 2010 ; Elliott, 2013).

Nationally, France has a history of using coastal spatial planning instruments with a regulation tool called 'Schéma de Mise en Valeur de la Mer' (SMVM). The key features of this marine spatial planning process was based on the cooperation of multiple partners including a development phase in which elected officials and all stakeholders (sector representatives and experts) are involved, with final approval by State representatives.

Thau has been a leader in France for ICZM planning with the first implemented SMVM in 1995 (Trouillet et al., 2011). In fact, the benefits of maintaining the water quality of the Thau lagoon have been evident since the ecological crisis of the 1970s, when 100% of the Thau lagoon waters suffered from an anoxic crisis due to eutrophication, which destroyed 100% of the shellfish farming stocks. To implement the WFD in transitional waters along the coastline and as stakeholder involvement in water management planning and public consultation has become mandatory for member states, the Languedoc-Roussillon (LR) region initiated in 2000 a new network to address eutrophication for coastal lagoons under the name Lagoon Monitoring Network (LMN). This network, with steering committee composed of five stakeholders of water and marine production management (the LR region, the water agency of the Rhône-Méditerranée-Corse basin, the DREAL as the state representative for environmental management, the Ceprelmar as the regional institute created in 1981 for promoting marine production that drives the LMN, and Ifremer as the partner for scientific research expertise), launched two 6-year contracts. The objectives were to build a eutrophication monitoring program of the lagoons of the LR region to deliver an operational Decision Support System (DSS) to local stakeholders to support their decentralized management of the lagoons.

In the meantime, the creation through a bottom-up strategy of SAGE-Thau (Schéma d'Aménagement et de Gestion des Eaux as the Thau River Basin Management Plan), driven by a local public body called the SMBT (Syndicat Mixte du Bassin de Thau), which acts on the behalf of the two largest intercommunalities of the Thau lagoon - CABT (Communauté d'Agglomération du Nord du Bassin de Thau) and CCNBT (Communauté des Communes du Nord du Bassin de Thau), has permitted the development of an integrated management of water quality in the Thau lagoon.

In fact, it is now well known worldwide and even locally that a common knowledge base between stakeholders, expert and scientists is requisite for implementing more elaborate forms of participation (Loubier et al., 2005; Rinaudo and Garin, 2005). The water quality restoration of the Thau coastal lagoon is the result of twenty years of several multi-disciplinary investigation programs alternately conducted by scientists and the local public bodies (e.g., OxyThau, EcoThau, PNEC, Omega-Thau, SPICOSA and so forth). DSS tools provided by the synthesis of these programs are currently used by the SMBT to produce indicators of water quality vulnerability (Mongruel et al., 2013). Some DSSs on lagoon water quality are provided, such as the one related to eutrophication, O'GAMELAG, or others related more to microbial contamination such as VigiThau. In parallel, other tools under development

propose to model how local territories, such as the Thau coastal lagoon, have promoted endogenous development based on Socio-Technical Information and Communication Arrangements at the scale of inter-municipal authorities to support mediation between heterogeneous actors which drives territorial intelligence (Bertacchini et al., 2013; Maurel et al., 2014, Plant et al., 2014).

Furthermore, the Thau coastal lagoon has kept its 'status' as a pilot site for ICZM through its nomination by the DATAR (Délégation interministérielle à l'Aménagement du Territoire et à l'Attractivité Régionale) interministerial delegation as a pilot site for the implementation of community regulations for ICZM strategies. Thus, in April 2013, an Integrated Management Contract (IMC) was signed for the Thau territory for the period 2012-2017. Its main objective was to provide coordination of all the management tools implemented in the territory including the preservation of Thau coastal lagoon water quality as the support of marine production.

Therefore, this paper aims to provide a reflection on climate-induced threats to integrated management of the Thau coastal lagoon and the multi-scalar adaptation strategy. It proposes first to depict the Thau water governance assessed through a water use and social network analysis and its capacity to manage water quality. Then, this paper provides a study of the downscaled climate change impacts on the hydrological budget of the entire Thau catchment in 2041-2070 compared with the 1971-2000 reference period. Following local climate change impacts, the importation of new waters to secure water uses is presented in regards to the capacity of local water governance to maintain coherence between integrated land planning and integrated water management planning based on the water quality issues of the Thau coastal lagoon.

Material and Methods

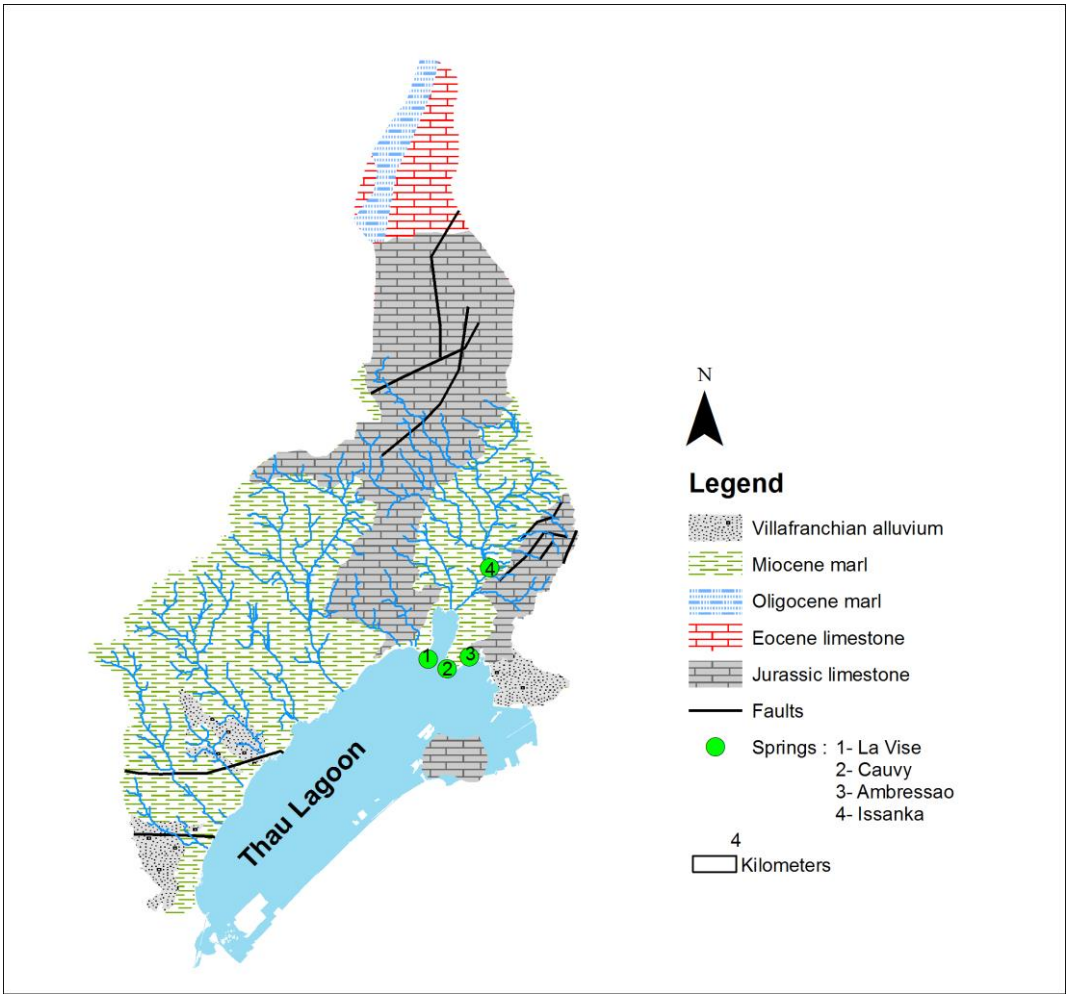
The Thau catchment – coastal lagoon hydrosystem

The coastal lagoon

The Thau lagoon is located in the LR region in the Hérault Department in the south of France. It is a 75 km² water body 19.5 km long and 4.5 km wide with a mean depth of 4 m and a high variability of salinity. Approximately one fifth of the lagoon's area (1,500 ha) is farmed for shellfish production, with shellfish farming occurring in three zones on the lagoon (Figure 2). It is also used for fishing.

The lagoon is in connection with the Thau karstic system which is made of complex karstic networks of Jurassic limestone with several inland and submarine springs (Figure 1). The latter plays an important

144 economical role since it supplies water for fish breeding, for the spa in Balaruc-les-Bains, and most
145 importantly, for some local drinking water supply (Pinault et al., 2004). Complex interactions between
146 the lagoon and the karstic system exist. For instance, seawater can occasionally inter the karstic
147 system through the spring conduits (Figure 1), depending on several factors including the hydraulic
148 head in the aquifer and in the Sea, rainfall event and water density in the aquifer (Pinault, 2004). This
149 phenomenon is locally known as *inversac,* and it can last for several weeks.
150 The frequency of anoxic crises, intensified during the second half of the 20th century (Elbaz-Poulichet
151 et al., 2004), is a consequence of both eutrophication levels (La Jeunesse and Elliott, 2004) and
152 particular meteorological conditions (Chapelle et al., 2000). Depending on the severity of the hypoxia,
153 it can lead to the destruction of shellfish stocks.



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155 **Figure 1: Simplified geological map of the Thau karstic system**

The catchment area

The Thau catchment covers approximately 280 km² (Figure 2). Almost 70% of the land devoted to agriculture is used for vineyards. Approximately half of the area's permanent population of 115,000 inhabitants is located in the city of Sète, situated on the southern shore of the lagoon. The population of the region is continuing to increase, and in summer tourists, mainly linked to the Mediterranean Sea side double the population of the area. A second French spa is located in Balaruc-les-Bains on the Thau coastline.

The catchment area is drained by a dozen intermittent small streams that flow directly into the lagoon. The Vène and the Pallas are the two main watersheds of the Thau, and they cover an area of approximately 67 km^2 and 54 km^2, respectively, representing approximately 54% of the total surface of the Thau watershed and accounting together between 50% to 80% of total freshwater inputs into the lagoon (Plus et al., 2006; Sellami et al., 2013).

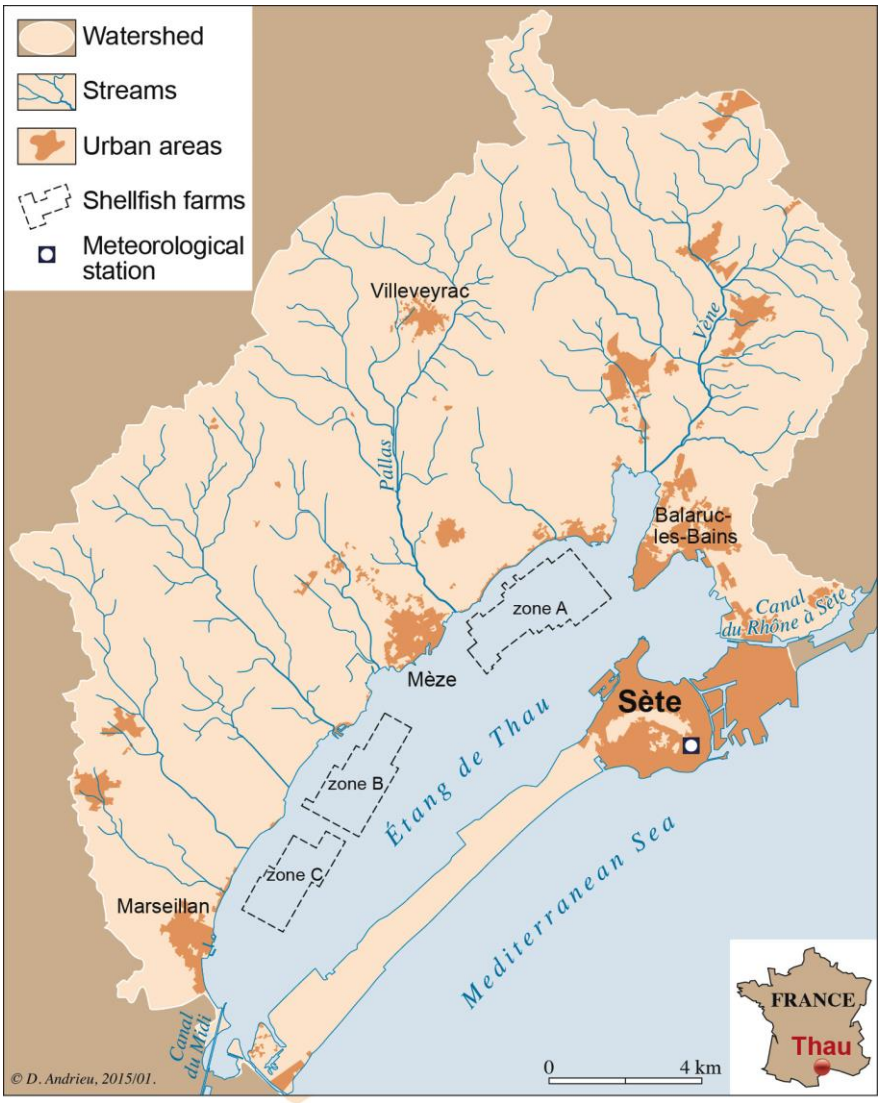


Figure 2: Localization of the Thau coastal lagoon and its catchment in the French Mediterranean coast

The local climate

The local climatic features were estimated from the historical observations recorded by the Météo-France meteorological station of Sète from 1970 to 2010 (Figure 2). This station is considered as representative for the whole catchment. This assumption is justified by the fact that the Thau catchment is rather small and quite flat; thus, it does not display significant spatial variability except for some orographic effects, which can be easily accounted for. The analysis of the 40-year time series in Sète revealed a marked inter-annual variability of the local precipitation climate. Indeed, the annual precipitation depth varies from 290 to 1000 mm, while the average is approximately 600 mm per year. Examining the monthly distribution more closely, precipitation displays a marked seasonal variability: precipitation occurs mainly during autumn and winter with frequent intense storms, whereas a long dry

period usually extends from the end of winter to the end of summer, with a minimum in July. The climatic distribution of monthly precipitation has been used to apply the final local-scale bias-correction as described later. The analysis of the temperature time series reveals that the hottest months are July and August and that daily temperature maxima exceeding 35°C are frequently observed, while the coldest months are December and January when daily minimum temperatures can sometimes be lower than -5°C (Sellami et al., 2013).

The French water management

At the hydrographic district scale, water agencies are responsible for the characterization of water bodies, public consultation, participation of water users in the water management policy, and preparation of the 6-year river basin management plans (called SDAGE) and programs of measures to implement the Water Framework Directive (WFD).

At the local level, the decision and implementation of water regulations strictly rely on the departmental prefects, who represent the central government at the administrative level. Then, state management is made through decentralized services: the DREAL (Regional Direction of Environment, Planning and Housing) and the DDTM (Departmental Direction of the Territories and the Sea).

At the sub-catchment scale, one of the main water management tools in France is SAGE. It is a planning document that pursues both quantitative and qualitative protection goals for water resources. When SAGE is approved, all decisions concerning water issues in the area must comply with its objectives. This legal status not only concerns the administration but also private individuals. It is developed by local actors (policymakers, users, NGOs, representatives of the state and elected people representing municipalities) together within the Local Water Commission (LWC). LWC has the status of an administrative commission without a legal personality. It organizes and manages the entire process of development, consultation and implementation of SAGE. It is an ideal place for dialogue, debate, advocacy and decision-making.

Since the urban planning law (SRU) of 2000, a planning document known as the scheme of territorial coherence, SCoT, has determined at a scale of several municipalities the general guidelines for land planning for the next 10 years. As urban planning and water management have common concerns, SCoT and SAGE require coherent ambitions. On the Thau territory, these two main local public policies instruments are driven by the SMBT.

The regional hydraulic management

The French use of regional Mediterranean water has through the centuries led to important hydraulic techniques for transferring water from regions with water availability to regions with important water needs that are not sufficiently supported. In this situation, the Rhône River represents the major river of the Mediterranean coast and was obviously the coveted river for pumping and transferring between catchments. A national company for managing the water transfer was created in 1955 by Philippe Lamour under the name CNABRL (Compagnie Nationale d'Aménagement Bas-Rhône-Languedoc). The project is for a vast irrigation network (canals and dams) that conducts water from the Rhône River with three departments (Gard, Hérault and Aude), allowing the development of diversified agriculture. A few years after extending hydraulic networks to the coastline of the LR Region, this water was also used for domestic use and thus tourism purposes.

CNABRL, currently called BRL, is still the regional partner for water management and for the regional climate plan. The strategic analysis center of BRL presents the water resources and water needs in France at the horizon of 2030 (BRL, 2006, 2012) which includes because of climate change, the need for more irrigation water in the LR Region. Aqua2020 proposed the project Aqua Domitia (Aqua Domitia, 2011) consisting of the extension of the existing Lamour channel to the city of Narbonne near the Spanish border. It has brought untreated water from the Rhône River directly to the Thau catchment since 2012. As the salinity of exploited surges in the Thau catchment has increased rapidly during the last several years, and the current drinking water plants connected to the Hérault catchment need to be updated, a new drinking water treatment plant started to treat water from the Rhône River in February 2012. Since then, local inhabitants have been drinking treated water from the Rhône River mixed with water from closer sources.

Regional downscaled climate change

The climate forcing used in this study was obtained in the context of a preliminary analysis conducted in the framework of the EU-FP7 CLIMB project. The first phase was devoted to the auditing of the outputs of 14 regional climate models (RCMs), which were run for the A1B emission scenario of the AR4 (IPCC, 2007) and were made available through the EU-FP6 ENSEMBLES project. A set of the four best-performing RCMs in reproducing the precipitation and temperature climates are considered (Deidda et al., 2013) while E-OBS products (Haylock et al., 2008) were used as reference. Daily

precipitation and the daily minimum/mean/maximum temperature time series in each grid point of the four selected models were first bias-corrected using quantile-quantile transformations to reproduce all the features of E-OBS climatology. Since the RCM grid resolution was approximately 25 km and thus not fully representative for hydrological modelling, the precipitation and temperature fields were further processed with downscaling and interpolation techniques. Specifically, the precipitation fields were downscaled to a 1 km resolution using the Space-Time RAINfall model (STRAIN) described in Deidda (2000), for which performance was tested in several contexts (e.g., Deidda et al., 2004, 2006). To account for the orographic effects, a modulation function was then applied as described in Badas et al. (2006). Temperature fields were instead interpolated at a 1 km resolution using the Barnes technique (Barnes, 1964, 1973) and the time-varying lapse-rate as described in Liston and Elder (2006). Finally, because the quantile-quantile correction with the E-OBS grid had the drawback of leaving residual biases at the local scale, a final correction was applied at a monthly scale using the local climatology estimated from the climatic station located in Sète.

Impacts of climate change on the Thau hydrological budget

To assess the impacts of climate change on the hydrological budget of the Thau catchment, the Soil and Water Assessment Tool (SWAT) hydrological model was selected. SWAT is a continuous and physically based hydrological model developed to study the effects of climate change and land management practices on water (Arnold et al., 1998). The model has been successfully applied to watershed modeling in the Mediterranean, particularly in the Thau catchment (Sellami et al., 2013, 2014). SWAT was implemented and calibrated against historical discharge data to estimate the water budget of the whole Thau catchment. Then, the model was driven by the ensemble projections of the selected climate models for a reference period (1971-2000) and a future period (2041-2070) to investigate the potential impact of climatic change on some hydrologic metrics, including changes in climatic conditions through assessing alteration in monthly precipitation and temperature previously described and changes in catchment flow regime through assessing changes in monthly runoff in the Thau catchment. Projected changes in climatic conditions for the future period were assessed by calculating the multi-climate models ensemble (CME) average relative deviation for monthly cumulative precipitation and absolute changes in monthly temperature with respect to the reference period (1971-2000).

Analysis of water uses and water use rivalries

In this study, the water managers are representatives of one category of stakeholders in charge of the water resource management and/or of its allocation. Following the Decree defining the Thau Local Water Authority composition, the number of water managers is about 26. The most relevant players, called key stakeholders, were contacted, and a questionnaire was built using the outputs of preliminary interviews with them. This questionnaire was composed of both closed and open questions (Beaud, 1996). The questionnaire was divided into 5 sections, containing a total of 32 questions for water users and 40 questions for water managers. A list of proposed and possible water uses was commonly defined for all the case studies of the CLIMB project. This list of water uses is provided in the x-axis of Figure 3.

Questionnaires have been implemented by an interdisciplinary team (geography, social anthropology, political science). Appointments were made with at least one person representative of each water use and water use management. To collect the maximum amount of information to analyze the water uses and water use rivalries, semi-structured interviews and completion of the questionnaires were performed for each stakeholder. A total of 21 qualitative questionnaires were collected, and 46 semi-structured interviews were recorded and analyzed (Table 1). In these 21 questionnaires, the main water uses of the area and the all the spatial scale of water management are represented, as shown below in the list provided in the Social Network Analysis.

Table 1: Implementation of the interviews and questionnaires in the Thau case study

THAU	Water managers	Water users	TOTAL
Preliminary interviews	17	8	25
Questionnaires submitted	23	20	43
Questionnaires filled in	11	10	21
Total of interviews	28	18	46

The first four sections of the questionnaire have been summarized and organized in a matrix with a column for each question and a row corresponding to each actor. The processing mainly consisted of regrouping the answers into categories and counting the occurrences to identify the major themes, terms, and answers that stood out. These outputs are used to present the major water uses and water rivalries according to stakeholders.

Then, the analysis was performed by listening in detail to the content of the interviews. Some additional information from the literature, supplemented by discussions with scientists of the CLIWASEC cluster, also contributed to the interpretation of results.

For more information on the content of the questionnaire or the on-site investigations, the reader can refer to the CLIMB reports on the CLIMB website (http://www.climb-fp7.eu).

Social network analysis of local water management

A social network analysis (SNA) was made on the basis of the 5th section of the questionnaire (Wasserman and Faust, 1994). The basic idea of SNA is to reconstruct stakeholder intervention in policy processes (Knoke, 1990). For focusing on the relations between individuals, groups and institutions, the SNA approach is particularly adapted to studying the actual interactions between multiple stakeholders in the field of water management and water access competition.

SNA measures betweenness centrality through the question of contact frequency. Betweenness centrality is the number of times an actor is on the shortest path between two other actors. It is the most prominent centrality measure used to study power and dominance as it indicates an actor's strategic position between other actors of the network. Actors having high 'betweenness centrality' have better negotiation potential and control over the flux of information within the institutional arrangement (Freeman, 1979; Christopoulos and Ingold, 2011). It gives insight here to the exact position and role (beyond the delegation of legal tasks) of the different managers and users in the integrated water resource management. Respondents were asked the following question: what is the frequency of your contacts with the following stakeholders (a list of all the groups of stakeholders interested with water use or water management was proposed. The acronyms relevant for the figures in the section presenting the results are: ADENA, Natural Reserve of the Bagnas Ponds; AE-RMC, Agence de l'Eau Rhône-Méditerranée Corse; Ass-Chasse, Association of hunting; CABT, Communauté d'Agglomération du Bassin de Thau; Cepralmar, Centre régional pour la promotion des activités de cultures marines; CAHM, Communauté d'Agglomération Hérault-Méditerranée; COVED, Wastes treatment society; CR-Conchy, Comité Régional Conchylicole de Méditerranée; CCNBT, Communauté des Communes du Nord du Bassin de Thau; DREAL, Direction Régionale de l'Environnement de l'Aménagement et du Logement; Ifremer, Institut Français de Recherche pour l'Exploitation de la MER; PRUD, Prudhomie des pêches de Sète-Thau; SDEI, Société de Distribution d'Eau Intercommunale; SIAE BL, Syndicat Intercommunal d'adduction d'eau des communes du Bas

Languedoc; SMBT, Syndicat Mixte du Bassin de Thau; Thermes, Balaruc-les-Bains spa). In the present analysis, we only consider frequent relations, i.e., monthly and weekly contacts. We assume that this frequency of contacts permits the identification of more active stakeholders of the local water network. The treatment of SNA has been achieved using Pajek software (Batagelj and Mrvar, 1998).

Results and Discussion

Local governance of the Thau water quality restauration

Perception of the hydrosystem by stakeholders

Shellfish farming emerged as the major water use for all the interviewed stakeholders (regardless of whether they were water users or water managers). Fishing is also considered as a major activity by water managers, whereas water users perceive it as less relevant and of the same importance as spa, domestic water, fishing and freight transport (Figure 3).

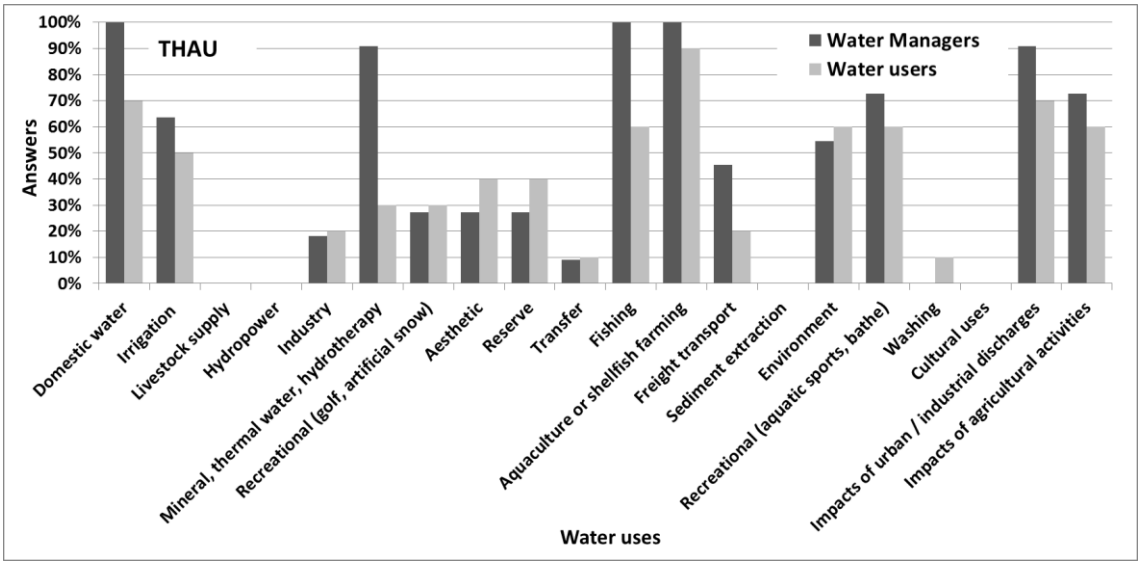


Figure 3: Major water uses of the Thau according to water managers and water users interviewed

There is a large difference in the importance of domestic use according to water users while, in fact, managers know this water use constitutes a significant portion of total water consumption throughout the basin.

It is worth noting that answers differ from water users and water managers for spa and freight transport. While almost all of the water managers interviewed considered the water use for spa to be major for the area, the water users considered it mainly as a minor use or did not consider it at all. The

answers regarding freight transport are mitigated and prove the lack of representation of the activities of the channel connecting Sète to the Rhône.

Environmental use, as a recreational use, is not considered by all the managers to be a major use; in fact, it was not even considered by water users. As rivers are all intermittent, except for mainly the Vène, which generally has a basic flow ensured by its link with the karstic network, the other rivers have no ecological flow to be maintained. The flow is generally represented by water treatment plant discharges. Interest for the rivers are not comprehensively mentioned even by environmental protection associations more focused on wetlands, biodiversity and water quality in the lagoon. Furthermore, the rivers are difficult to access and do not attract any recreational use on the catchment area. This contrasts with the answers for the consideration of the point and diffuse pollution impacts considered as major for both water managers and water users. Livestock, hydropower, recreational, aesthetic, reserve, washing and cultural uses are not mentioned as major.

One can also highlight the absence of the perception of water transfer in this area for both water managers and water users. The transfer of water is mentioned only once as a major water use which proves that the local water management is really concentrated on the Thau lagoon and does not address the problems and pathways related to water transportation and treatment for drinking usage, despite the fact that the Aqua Domitia project was already initiated during the interview period. This is in part also due to complex interconnections of the new water transportation plants that make it difficult to know exactly where the water is coming from.

The Balaruc-les-Bains spa is the second most important French station. The exploitation of deep surges is dependent on the state of the karstic aquifer; thus, because of the inversac phenomenon already described, great difficulties have been experienced in the past due to conflicting requests from fishermen and spa water users.

A point which is also far from the situation within the case study concerns the importance of industry in the territory according to stakeholders. The Thau lagoon is lined with chemical industries for the production of fertilizers and a factory for concrete. Moreover, the plants of these industries are particularly visible around the lagoon. However, stakeholders from these industries have all declined our solicitation for this study. The absence of industries in the LWC can also been mentioned even if they are officially perceived as being represented by the CCI (Chamber of Trade and Industry).

The social network of the local water management

The intensity of contacts between stakeholders is represented in Figure 4. Highly connected stakeholders include the following: DREAL and the water agency (AERMC) which represent local state representatives and are directly concerned by the implementation of the WFD; SIAEBL is the most importation water production syndicate for the Thau territory; SDEI coordinates wastewater treatment; CABT and CCNBT are the two main groups of municipalities of the Thau territory; Ifremer is a research Institute that locally investigated the surveillance of water quality of the Thau lagoon and the safety of shellfish for commercialization; Cepralmar is the regional center for promoting the production of marine cultures; and CR-Conchy is the regional council for the marine cultures survey, while PRUD is the local representative of marine culture activities.

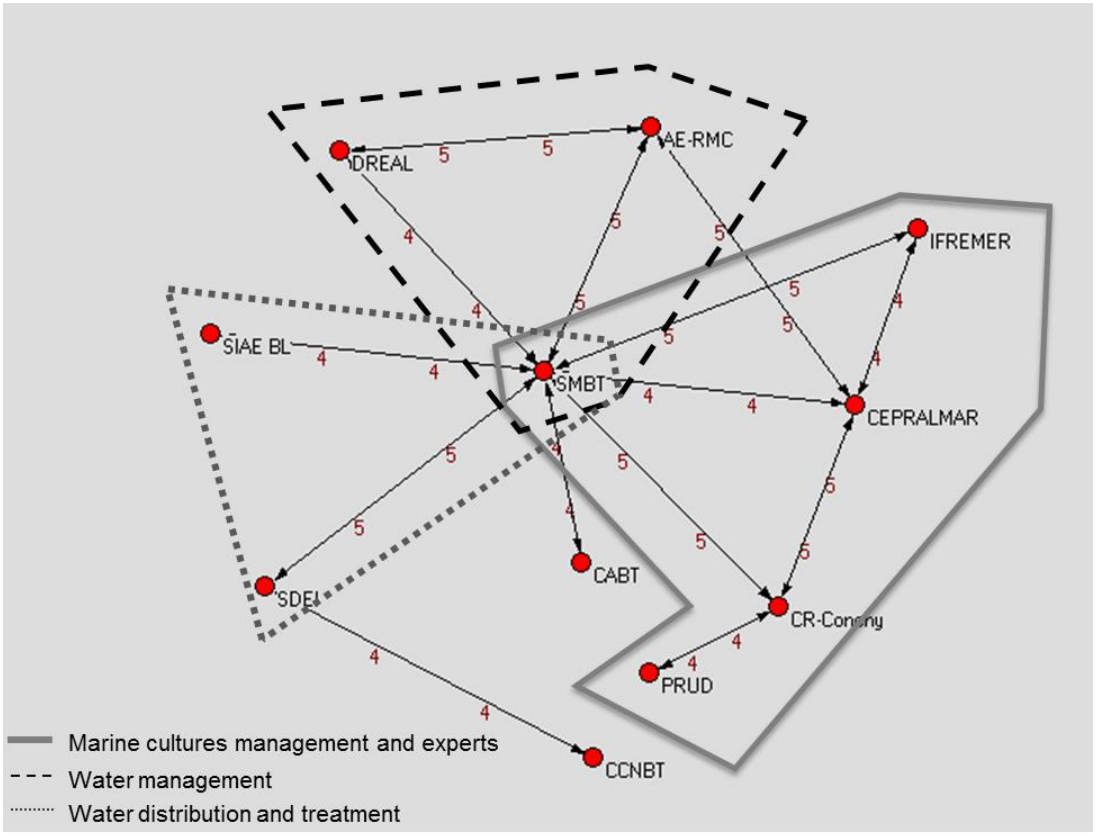


Figure 4: Betweenness centrality within the water social network. The frequency of contacts represented is monthly for the value 4 and weekly for the value 5. Acronyms are defined in the section presenting SNA methods.

The graph in Figure 4 reveals that water uses and water managers are highly connected (weekly contacts with the value 5 and monthly contacts with the value 4). Stakeholders are in direct and frequent contact with SMBT (eight nodes) except for CCNBT. However, such absence of a link

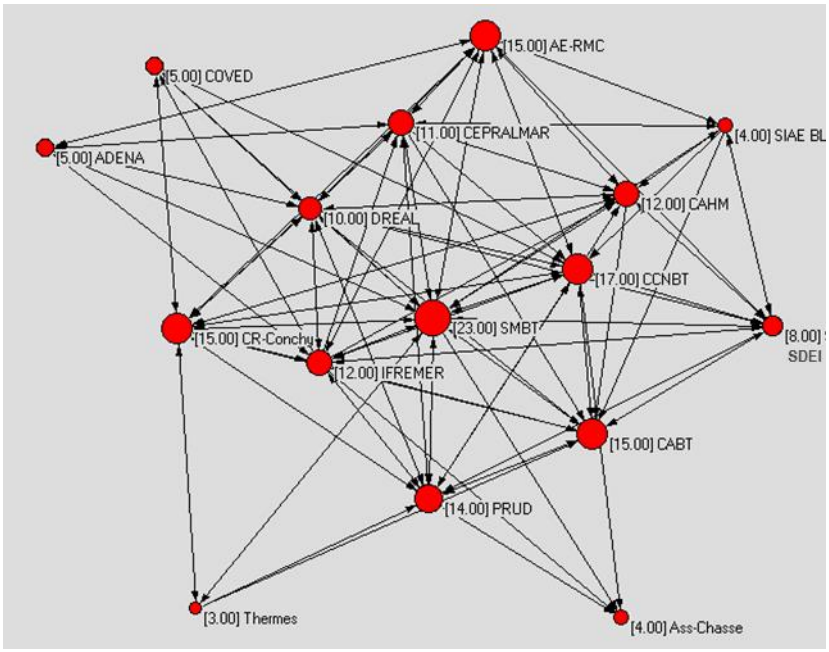
between two stakeholders does not mean a complete lack of connection, just rather occasional connections. SMBT has the highest betweenness centrality making it in a very influential position as it connects many stakeholders together. Three other stakeholders have three nodes of connection: Cepralmar, AE-RMC and CR-Conchy. These are key stakeholders for the network as they provide contact with other parts of the network.

The analysis shows that SMBT is the only stakeholder which connects three sub-networks: (i) the first handles marine production comprising shellfish farming and brings together research expertise on both environmental and farming issues (Ifremer) and local and regional managers of marine production (PRUD, CR-Conchy, Cepralmar); (ii) the second relates to water management with water policy implementation (AERMC, DREAL); and (iii) the third addresses drinking water production and supply (SIAEBL, SDEI) and waste treatment. Communities of communes (CABT and CCNBT) can be considered more external to these sub-networks and are connected through SMBT. SMBT is the most central and influential stakeholder as it connects, directly or indirectly, all the local stakeholders. This position is confirmed by the importance of transfer of information as shown Figure 5 and Figure 6, SMBT is central both for the centrality in (they receive information from the stakeholders of the water network, Figure 5) and the centrality out (they provide information to stakeholders of the water network, Figure 6).

What is also important is that sub-networks (i) and (ii) represent the Lagoon Monitoring Network (LMN). This network, established in 2000 to diagnose, on the basis of a set of several indicators, the different ecological statuses of compartments of lagoon ecosystems in 23 lagoons of the LR region. This network objective was clearly presented as a way to build governance on a network linking managers and scientists. The fact that LMN was hosted by Cepralmar also complies with the priority given to the use of the lagoon waters for shellfish farming. In fact, this water use, as one of the most exigent regarding water quality and economically very important for the territory, was considered to integrate all water uses of the catchment and coastal lagoons.

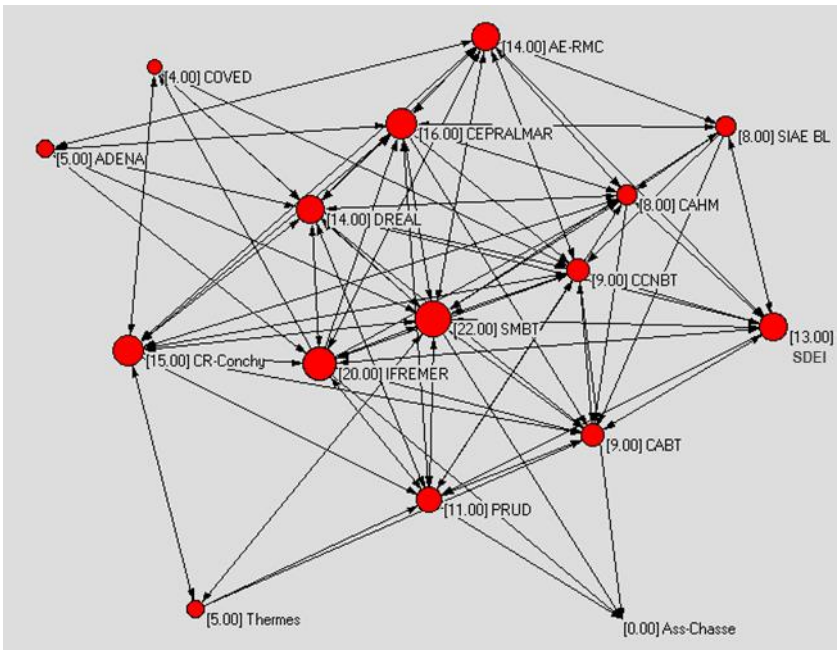
In summary, SNA confirms the central position of SMBT and the strong focus of water management towards lagoon water quality and shellfish farming. The Water Agency (AE-RMC) nevertheless keeps a prominent role in local water management issues. The governance of network type is very important in the local water management of the Thau catchment, and it involves a mix of public and private

416 actors, including municipalities and the regional water basin authority on the public side. The French
417 government (DREAL) has a relatively peripheral position.



418

419 **Figure 5: Centrality in for stakeholders in the Thau case study. Numbers represent the number of arrows**
420 **directed to the node. Acronyms are defined in the section presenting SNA methods.**



421

422 **Figure 6: Centrality out for stakeholders in the Thau case study. Numbers represent the number of arrows**
423 **directed from the node. Acronyms are defined in the section presenting SNA methods.**

424 ## Does climate change threaten the Thau territory?

Climate change impacts on the Thau territory

While the projected precipitation closely follows the seasonality and the monthly variability of the reference period, there is a clear tendency to a generalized decrease in the magnitude values across all months over the Thau catchment (Figure 7). This reduction is expected to range from -14 to -2% according to the CME mean values. An exception is made for February where the mean trend projects an increase of +5% in precipitation. However, the CME uncertainty interval suggests further decrease ranging from -18 to -5% from September to December, from -14 to +10% from January to April and from -15 to -2% in late spring and during the summer months. These values reflect the large uncertainty and variability in CME projections particularly in the winter months.

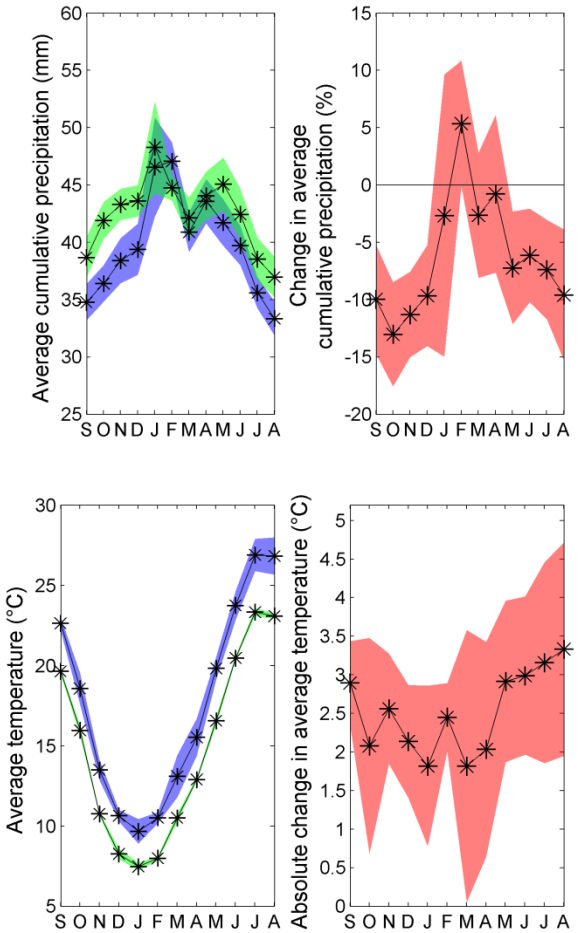


Figure 7: Projected change in reference cumulative precipitation (upper panel) and average monthly temperature (lower panel) as predicted by the ensemble multi-climate models in the Thau catchment. Light gray (green) represents the reference period (1971-2000) and dark gray (blue) represents the future period (2041-2070). The black line with black stars refers to the mean value.

When comparing the magnitude of the average monthly temperature projection with that of the reference period, there is clear evidence that climate models become more uncertain in simulating temperature in the 2050s. All climate models project a general tendency towards warmer conditions over the Thau catchment. The projected magnitudes of change suggest that the reference monthly temperature is likely to increase by 1.7 to 3.2°C depending on the season. The highest increase in temperature is projected for summer months when the summer season (JJA) reference average temperature will increase by 3.1°C in the 2050s according to the mean value of CME. In contrast with precipitation, the projected uncertainty in the magnitude of change in temperature decreases from the dry months to the wetter months. By considering the uncertainty range of the values, the average monthly reference temperature is likely to increase by 2 to 4.6°C in summer, 1 to 3°C in winter, 0.1 to 4°C in spring and 0.7 to 3.4°C in autumn.

These new warmer conditions would exacerbate the evapotranspiration process with a potential increase in irrigation needs. In the meantime, the water balance will also decrease with decreasing precipitation, with implications for runoff. Indeed, there is a clear tendency to less runoff in the future with respect to the reference period in the Thau catchment (Figure 8), with a marked decrease in the wet months, from October to December, with an average reduction of -20% with respect to the reference value. Summer monthly runoff is also expected to decrease with an average value of -8%. However, there is an increasing uncertainty in the projected relative change of the reference runoff from the dry period to the wet period. Runoff is expected to decrease in the 2050s by a range between -13 and -3% in summer, between -33.8 and -1.8% in winter (without considering February), between -31 and -5.5% in autumn and between -10.3 and -2.2% in spring.

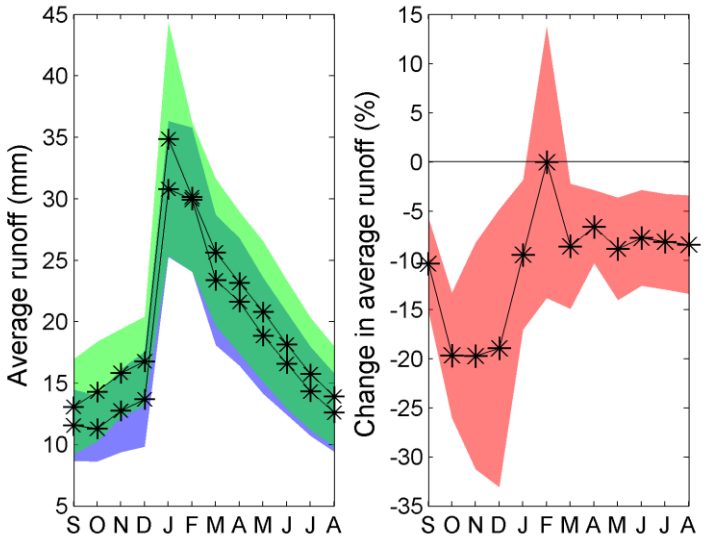


Figure 8: Projected change in reference runoff as predicted by the ensemble multi-climate models in the Thau catchment. Light gray (green) represents the reference period (1971-2000) and dark grey (blue) represents the future period (2041-2070). The black line with black stars refers to the mean value.

In general, due to the combined decrease in precipitation and increase temperature, it is very likely that the Thau catchment will experience a general tendency toward less availability of freshwater in the future with respect to the reference period. This will induce a decrease in freshwater input into the lagoon and probably an increase in water salinity. Moreover, these results do not consider the possible additional impacts of the decrease in runoff on the recharge of the karstic aquifer in both baseline discharge in the Vène River and the on unassessed volumes of freshwater entering the lagoon via underwater springs as the Vise aforementioned.

Rivalries between water uses

First, all water uses mentioned are potentially in competition with one another in the Thau lagoon. The only use which does not generate any mention of dispute or competition is industrial use.

There are many disputes in the Thau lagoon, and the list of rivalries provided by stakeholders is mainly related to water quality in the lagoon. The disputes mentioned all date back to less than 10 years. One user mentioned 1975-1990 as a period in which water quality worsened significantly and when major anoxic crises in the lagoon started, affecting all uses of the lagoon with major conflicts. This user also explains that this gave rise to initial discussions between users.

The biggest number of responses refers to shellfish activity in the lagoon, and this is mentioned both by managers and users. The problems mentioned are those related to the loss in production or the

inability to sell shellfish due to water quality problems in the lagoon (microbial contamination and anoxic crises due to eutrophication). These problems are described as being not completely resolved; also, the awareness of these problems is improving following a number of study and research programs undertaken to predict and anticipate crises and which involve decentralized government services and local authorities.

The spa activity in Balaruc-les-Bains is also mentioned by both users and managers as provoking frequent disputes with fishermen. The inversac phenomenon is always associated with problems, although the complexity of this phenomenon makes it difficult to clearly identify causes for stakeholders. While the spa is the more impacted activity during inversac, fishermen consider the spa to be partly responsible.

Tourism is also mentioned both for its impact on water quality (due to urban waste or directly in the lagoon due to recreational boats) and for the necessity to preserve bathing water quality in the lagoon. Although the description of the impacts is vague, this use is perceived to be routing water away from other activities: spa, environmental and freshwater users highlight the need to fight against salinization of the lagoon in the summer. Irrigation seems to be a very local problem only in one town (Villeveyrac). The impact of ferti-irrigation of vineyards using chemical products and the need for acids to clean the pipes is described in detail. The problem concerns both competition for the resource and the cause of pollution.

As for issues unrelated to conflicts of use, the impact of the increase in salinity of water on fauna and flora is mentioned without further detail.

As far as the described rivalries between water uses in relation to the quality of the waters of the Thau coastal lagoon, climate change impacts, such as an increase in temperature and salinity of the waters, are perceived to probably aggravate tensions between water users.

The regional water scarcity adaptation strategy including Thau territory

In the Thau territory, demographic pressure is increasingly tough, not only because of the influx of tourists but also due to the resident population. The latter has particularly accelerated since the building of the strip of the A9 motorway which connects Nîmes, Montpellier, Béziers, Narbonne and Perpignan to Spanish Catalonia via the Pyrenees. In fact, Montpellier is an employment hub, whereas the basin of Thau has a high rate of unemployment; however, housing costs are very high in Montpellier and its neighboring suburbs. The villages in the Thau basin are therefore highly sought

after as they are less than 40 km from Montpellier. The water sources of the catchment area have never been sufficient to supply the population. Water from surges and aquifers has been imported from the Hérault area for several decades with the exploitation of local surges currently degraded by an increasing salinity. However, as mentioned above, in February 2012, water was routed from the Rhône River within the framework of the regional Aqua Domitia project for distribution after treatment by the SIAEBL Water Syndicate. This project shows how domestic use represents an important part of water uses in the basin and how dependent the basin is now on external regions, despite being in the same hydrographical district in view of the WFD.

Coherence between regional and local water governance

The great *malaïgue* of 1975 of the Thau coastal lagoon, an anoxic crisis related to eutrophication of waters which affected the entire lagoon with the loss of all shellfish that had been bred, led all local policies to focus on the necessity to recover the water quality of the lagoon to support one of the main economic activities of the Thau territory: shellfish farming and fishing justified for its major input to the socio-economic life of the region. A SMVM has been implemented to work on resolving conflicts due to the diversity of human activities in the coastal zone, representing the intention to develop ICZM around the Thau lagoon ecosystem. Scientific investigations of the quality of the lagoon were set up in interaction with the study of the impacts of human activities from the catchment to understand the connection between human activities and water quality of the lagoon. At that time, eutrophication was the main threat according to nitrate (Plus et al., 2006) and phosphorous load assessments (La Jeunesse et al., 2002; La Jeunesse and Elliott, 2004). The need to comply with the WFD permitted the structuring of scientific data on the transitional waters of the LR Region through the regional initiative to launch the LMN.

Presently, the work to provide an integrated vision of the water quality of the hydrosystem by the SMBT has been a success as proven by the results presented here as (i) the capacity of all stakeholders groups to make the link among water quality of the coastal lagoons, outputs from the catchment and the support to shellfish farming and fishing activities; (ii) the intensive local water network around the cornerstone actor SMBT which drives an efficient governance for the restoration of water quality; and (iii) the dissemination of knowledge to all stakeholders through activities of the LMN. The high quality database on the ecological quality of regional coastal lagoons maintained by the LMN permitted the implementation of the LOICZ (Land-Ocean Interactions in the Coastal Zone)

biogeochemical budget methodology (Gordon et al., 1996) and led to the DSS tool called O'GAMELAG (LMN, 2013). This DSS has been implemented in one regional coastal lagoon, Bages-Sigean, and it was planned to for implementation in the Thau coastal lagoon. Those data are even largely used to perform environmental impact assessment studies in the region by several public and private bodies comprising Natura 2000 assessments. Thus, this database is supporting analysis to preserve both the good ecological status of the lagoon in relation to nutrients and the shellfish farming production in the context of urban development in the catchment. This high level of connection of stakeholders is the result of twenty years of collaborative actions between stakeholders on the support of scientific expertise. Local citizens still remember the difficulties of awareness and negotiations steps, including several important local crises as the destruction of the Ifremer research center in 1987 by shellfish farmers who were, at that time, not aware of the new water quality issues in the coastal lagoon. Communication among all water uses has been the only support of the integration of water quality, but it has been supported day after day by relevant databases and models developed and presented by local experts and grouped in LMN. Additionally, this capacity to restore water quality is due to the dynamism of the SMBT to drive the local network because of its singular position as it acts on the behalf of CABT and CCNBT.

This permitted the provision of a SCoT coherent with the SAGE. SAGE and SCoT both consider water uses and water quality issues related to shellfish farming as the criteria of integration. Then, SMBT provides clearly, even on its website, the need to control urban development on the territory to prevent its possible unsustainable impacts on water quality of the Thau lagoon.

In this context, the provision of an 'unlimited' water resource to sustain the drinking water production of the Thau territory by the new hydraulic connections and the forecasted regional mutation of agricultural practices raise questions. This seems incoherent with the control of the urban spread and the regulation of human activities development at risks for water quality. Environmental and long-term water management concern have been clearly exposed during the public debate on Aqua Domitia project as for the main points of the list relevant for the Thau territory: the decrease in awareness of water economy, the heterogeneity for farmers to access to this new resource, the switch from several to one unique source of water for drinking water production as local communities could not afford to invest in both the maintenance of the old production system and the treatment of the water coming from the Rhône River, the use of water by industrial instead of agricultural activities that has justified

investments for bringing water initially for irrigation, new water quality issues in the water bodies induced by contaminants contained in water for irrigation such as PCBs and diuron that are a very recent concern for the Thau lagoon, the intrusion of new pesticides in the drinking water even if they remain on legal concentration after dilution with unpolluted sources of water, and so forth.

One interesting question for this paper was related to the governance of Aqua Domitia. The need for trans-basin governance induced by the specificities of the Aqua Domitia project is claimed by stakeholders with particular insistence from water managers. If the LR region recalled the vocation of public interest, BRL, as the dealer, some participants do not state less distrust toward the potential market behavior of this company. Furthermore, some studies have revealed the under-exploitation of the water already dedicated to irrigation, and this could have been interpreted as an already existing safety margin in the context of climate change impacts (Ghiotti and Honegger, 2009).

In the meantime, the Thau agglomeration (CABT) presented Aqua Domitia as a response to the specific challenges of their territory. SAGE-Thau, which also participated in this public debate, used to support Aqua Domitia project explaining it as the only way to ease pressure on the fragile aquatic water bodies following studies conducted by the Water Agency. In fact, the impact of climate change on the Thau hydrosystem which would manifest in a decrease in freshwater outputs from the catchment to the coastal lagoon and its associated wetlands has even been confirmed by this study.

SAGE-Thau also defended the position of the absolute need to clarify the governance of this new resource, and thus we think the establishment of regional versus local water governance will be challenging in the coming years.

The 184 pages of this public debate report induced 3 pages of synthesis of the decisions from BRL. The most important one for the Thau territory is that BRL has decided to participate, together with the LR Region, in deploying a system of consultation with stakeholders and public information including strengthening the system of information on water quality in collaboration with experts of reference in the field of water quality. Thus, the network of stakeholders is equivalent to that represented the LMN! However, because the LMN reached its goal of delivering an operational DSS to local stakeholders, the LR region decided to end this network by not providing any financial support (representing less than 300,000 euros per year) to a new plan of action. LMN ended in 2013, and the DSS O'GAMELAG will not be implemented for the Thau stakeholders.

Thus, whereas (i) France has to answer to the European Union for its lack of a definition for vulnerable areas related to the Nitrates Directive in the Thau catchment; (ii) the Thau catchment is ungauged despite being regularly mentioned as a pilot site for integrated management in the coastal zone with the creation of hydrological indicators; and (iii) the Thau territory has initiated a period of evolution of the local water resource governance; the LR Region has denied local authorities of adequate scientific expertise. The water quality expertise is no longer organized as one voice in the water network, and the knowledge on several lagoons is no longer capitalized to deliver a consistent message on the state of ecological quality of regional coastal lagoons necessary to provide new indicators to face climate change impacts on the hydrosystem. Perhaps the next directive on Marine Spatial Planning and Integrated Coastal Management would permit the network to re-establish, but, in any case, this situation is a proof of the lack of awareness of climate change-induced impacts on local territories. Thus, scientists have to continue their efforts of disseminating their results as highly requested, at least, by the European Research Framework programs.

Conclusions

The results of the study presented in this paper expose that rivalries which took place in the past in the Thau coastal lagoon are declared by stakeholders to be related to water quality issues in the lagoon. Today, the water quality restoration is the result of twenty years of several multi-disciplinary programs alternately conducted by scientists and by the local public bodies. Moreover, this has been possible through two main factors. Firstly, as confirmed by the SNA outputs, through the central position of the public body SMBT and the strong focus of water management towards lagoon water quality and shellfish farming. Secondly, through the creation by the LR region of the LMN in 2000 to provide a common knowledge base between stakeholders (both water users and water managers), experts and scientists for implementing integrated management solutions for the transitional waters.

Climate change is likely to bring the context of relations between users of the water resource in tense situations similar to those happened in the past. Specifically, 2050s projections indicate that yearly mean precipitation is expected to decrease from about 2% to about 15%, while conversely temperature is expected to increase on average from about 2°C to about 3.5°C. The temperature increase will exacerbate the evapotranspiration process, leading to a dryer soil moisture conditions, which will require larger water quantity for irrigation, while precipitation decrease will be obviously

reflected in lower runoff production. These critical changes will imply potential negative impacts on water quality comprising anoxic crises.

In order to answer to climate change impacts, the LR region managed the Aqua Domitia project to conduct freshwater from the Rhône to the Thau catchment to supply irrigation needs. This water is already used for drinking water production supplying industrial, domestic and tourism water uses. While the SMBT is devoted to control the urban spread and the regulation of human activities development on its territory with the two main tools represented by the SCoT and the SAGE Thau, this provision of an “unlimited” water resource can be considered as incoherent. Moreover, as this paper demonstrates, the absence of perception of both water transfer and climate changes impacts, the dissemination of threats due to climate change and the use of the untreated water of the Rhône River or the water quality of the lagoon is really needed. The specificities of the Aqua Domitia requires a trans-basin governance which could have relied on the existing LMN. However, the LR region decided to end its financial support to the LMN in 2013! Since then, stakeholders no longer have contact that can meet with an integrated approach to their problems. More importantly, the methods used to resolve situations in the past could be inefficient for future situations. In the present state of knowledge on the impact of climate change, it is likely that the chains of cause and effect for achieving the same situation of deterioration of water quality are different. Thus, the tools previously developed, including those offered by the LMN, although operational and valid today for some regional coastal lagoons, can become obsolete if not updated continuously with the increase in knowledge about all the criteria explaining the chain of cause and effect between climate change and water quality.

The political decision to end this network, beyond demonstrating a lack of appreciation of the issues of the territory, can be much more problematic for some time as it will induce rearrangements of this network. There is every reason to think the establishment of regional versus local water governance will be challenging in the coming years. Indeed, by denying the territory to continue in developing its own methods of water quality management, it increases the risk of development outside the challenges of climate change, that is to say, unsustainable development or maladaptation. This contributes to increase the vulnerabilities of the Thau territory to climate change impacts.

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